Now that most of the experimental element has been removed from this simple procedure it is hoped that more amateurs, particularly beginners, will be encouraged to construct their own filters, especially when inflation has placed commercial products almost beyond reach.

Acknowledgements

It is wished to acknowledge the many sources of information listed in the references, all have made their own contribution to an understanding of ladder crystal filters, without which the simplified method of predicting filter bandwidth could not have been developed.

It is also wished to acknowledge the expert assistance of Miss A. E. Howarth for carrying out literature searches and making translations.

References

[1] "Some experiments with high frequency ladder crystal filters", J. A. Hardcastle, G3JIR. *Radio Communication* December 1976, January, February and September 1977.

[2] "Formulas for the calculation of narrow bandpass filters with identical piezoelectric crystals and maximally flat attenuation behaviour", J. E. Colin (in French). *Cables and Transmission,* Vol 22, April 1968, pp132–5.

[3] "Crystal ladder filters", J. Pochet, F6BQP. In "Technical Topics" *Radio Communication* September 1976; *Wireless World* July 1977.

[4] "Narrow band filters", P. Amstutz (in French). *Cables and Transmission,* Vol 21, April 1967, pp88–97.

[5] "Modern network theory design of single sideband crystal ladder filters", M. Dishal. *Proc IEEE,* Vol 53, September 1965, pp1205–16.

[6] "Technical Topics", J. P. Hawker. *Radio Communication* September 1977, p693.

[7] "Direct coupled resonator filters", S. B. Cohn. *Proc IRE* February 1957.

[8] "Narrow bandpass filters using identical crystals designed by the image parameter method", J. E. Colin (in French). *Cables and Transmission,* Vol 21, April 1967, pp132–5.

[9] "Modern filter theory and design", editors G. C. Temes and S. K. Mitra, Chapter 4 "Crystal and ceramic filters", G. Szentirmai.

[10] Private communication, J. Haine, ex-G8CEG, 22 April 1977. □

Power transformers with low voltage secondaries

by G. C. OXLEY, G8MW*

Introduction

Transistors usually operate at lower voltages and higher currents than thermionic valves, but new transformers are costly, and are not always available to suit particular requirements. The heater and ht windings of old mains transformers can sometimes be removed without disturbing the primary windings, and the required secondary winding can then be wound on by hand. Much design data has been rendered out-of-date by the adoption of SI units and the use of newer insulating materials.

Core size

Fig 1 shows the power handling capacity of transformers for different cross-sections of core; these are conservative ratings.

Because the core is laminated, the actual cross-section of the iron will be approximately 10 per cent less than the physical area. As an example, a 2·54 by 2·54cm core (1in by 1in) will only have an iron area of 5·9cm^2 (0·9in^2).

Turns per volt

The number of turns needed depends upon the cross-sectional area of the core, the mains frequency, and the magnetic flux density. A frequency of 50Hz, sine wave, and a flux density of 0·8Wb/m is assumed. Table 1 gives the number of turns per volt for the different core sizes.

*Osterwald, Littlemoor, Ashover, Chesterfield, Derbyshire.

Wire size

The windings must be able to carry the required current without over-heating or damaging the insulation; newer insulating materials allow higher temperatures. The thicker the wire the smaller the I^2R loss, but this means fewer turns in a given space. Current densities quoted in various handbooks are given as 1,000, 1,500, 1,750 and even 3,000 A/in^2; the metric values of 2·5, 3 and 3·5A/mm^2 are much easier to deal with, 2·5A/mm^2 corresponds roughly to 1,600A/in^2, and this value

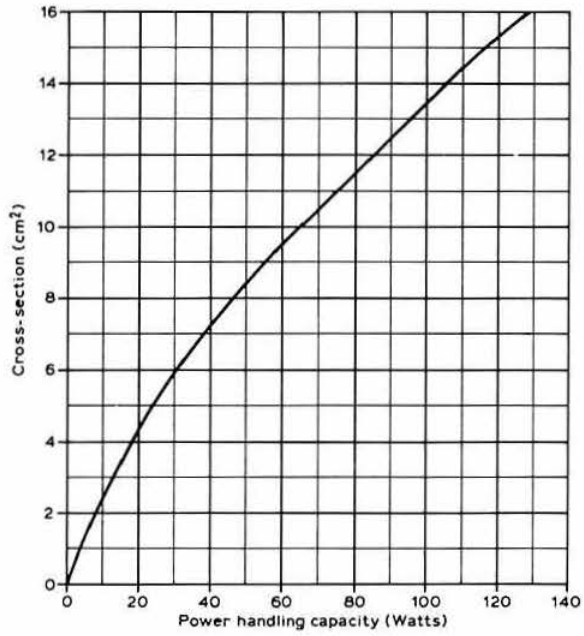

Fig 1. Power handling capacity of transformers for different cross-sections of core

Table 1

Cross-sectional area cm²	Cross-sectional area in²	Turns per volt
	0·5	14
4	0·62	11
	0·7	10
6	0·93	7·5
8	1·25	5·6
	1·5	4·7
12	1·85	3·8
16	2·5	2·8
20	3·1	2·3
24	3·7	1·9
	4	1·8

Table 2

Diameter mm	Wire Cross-sectional area mm²	Nearest swg	Current carrying capacity 2·5A/mm²	3A/mm²
0·25	0·05	34	100mA	150mA
0·315	0·08		200mA	240mA
0·4	0·13	28	325mA	390mA
0·5	0·2		500mA	600mA
0·56	0·25	24	625mA	750mA
0·71	0·4	22	1,000mA	1,200mA
0·8	0·5	21	1·25A	1·5A
1·0	0·8	20	2A	2·4A
1·25	1·2	18	3A	3·6A
1·5	1·8	16	4·5A	5·4A
2·0	3·25	14	8·1A	9·75A
2·5	5	12	12·5A	15A

is recommended, for reasons given later. When a single- or double-layer winding is exposed to the air (on the outside of the spool) one of the higher figures can be used; Table 2 sets out some typical values.

Example: wire diameter 0·71mm, wire cross-sectional area 0·5mm², therefore current at 3A/mm² = 1·5A.

One supplier gives a figure around 4A/mm². This is admissible if the windings are on the outside, can be kept cool, and are supplying a resistive load.

Power factor and waveform

Some of the energy supplied to a transformer is returned to the mains, and is represented by the reactive component of the primary current—one ought really to speak of the rating of a transformer in volt-amps. This reactive current, although comparatively small, does help to heat up the windings, and about

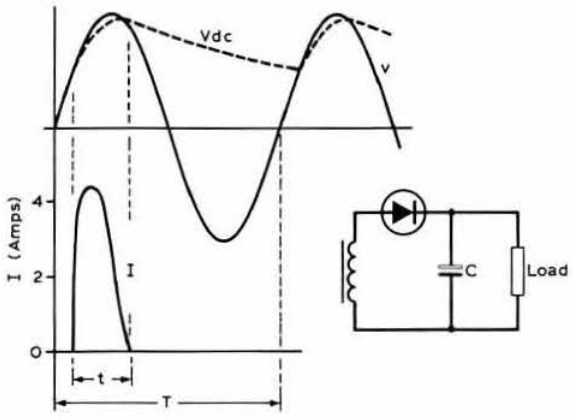

Fig 2. With a large reservoir capacitor and a half-wave rectifier, current only flows during time t over the period of one whole cycle T

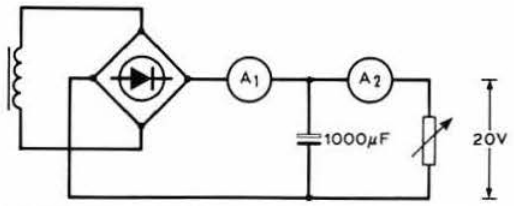

Fig 3. Circuit to show the heating effect of a pulse current

five per cent should be allowed for this when choosing the size of wire.

A more serious consideration is the rms value of pulses supplying a rectifier which has a large reservoir capacitor. As an example, consider a half-wave rectifier: Fig 2 shows that, over a period of one whole cycle T, current only flows during time t. To make the calculations easier, but nonetheless valid, let the pulse of current be a square-wave of amplitude 4A. The average value over the whole cycle will be 1A; because T = 4t. This is the current which would be read on a moving-coil meter.

The square-root of the mean of the squares of the instantaneous values of current, rms, will be

$$\sqrt{4^2 \div 4} = 2A$$

The heating effect of this current is four times that of the average value of current.

Full-wave (bridge) rectification, with as small a reservoir capacitor as possible, will keep the transformer loading within its rating. A further advantage of full-wave rectification is that the transformer core does not become magnetically polarized; this reduces switching transients.

In the experimental circuit shown in Fig 3, A1 is a 0–5A moving iron ammeter which reads rms values, and A2 is a moving coil ammeter (Avometer). The load resistor was adjusted until A2 read 3A, and the reading on A1 was 4·2A. The heating effect of this pulse current is just about double that of the rms value of a sine-wave. This is the reason why the recommended wire sizes are on the conservative side.

Practical considerations

Insulate between layers using thin sheets of paper. Cut plastic adhesive tape lengthwise and use to cover the windings close to the cheeks of the bobbin. The final layer can be doped with polyurethane varnish.

The core should be clamped as tightly as possible and then given a coat of black paint.

After the old secondary windings have been removed, an electrostatic screen may be found interposed between the primary and secondary windings. This may be of copper or aluminium foil and is usually connected to the core and to earth. The ends of the screen must be insulated, otherwise the screen may form a short-circuited turn. Two layers of good insulating tape should be wound over the primary. A further two layers should be wound over the screen. This screen helps prevent mains-borne interference.

Bibliography

The Radio Amateurs Handbook, ARRL 1949.

Practical Design of Small Motors and Transformers, E. Molloy.

Handbuch für Hochfrequenz-und-Electrotechniker, C. Rint, Berlin.

Electrical Engineers Handbook Pender, McIlwain. □